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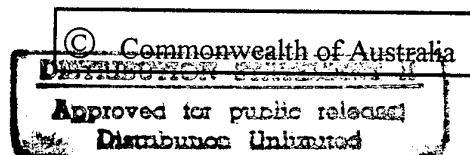
Safety Distance Calculations for
Multi-Item Fragmenting Munitions

D.A. Jones and G. Kemister

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Safety Distance Calculations for Multi-Item Fragmenting Munitions

D.A. Jones and G. Kemister

**Weapons Systems Division
Aeronautical and Maritime Research Laboratory**

DSTO-TR-0505

ABSTRACT

The destruction of unwanted munitions is a continuing activity for Army. The Defence Explosives Safety Manual specifies formulae which prescribe a significantly increased safety distance for a multi-item demolition compared to a single item of similar size. In practise this means that in many situations munitions can only be disposed of singly, which is both costly and time consuming due to the safety procedures required between each blast. This report examines the basis of the formulae and recommends a charge configuration which will enable multiple munitions to be disposed of in a single detonation.

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Safety Distance Calculations for Multi-Item Fragmenting Munitions

Executive Summary

The destruction of unwanted munitions is a continuing activity for Army. Explosives can be destroyed either by detonation or burning, and these procedures can only be conducted on approved burning and demolition grounds. The Defence Explosives Safety Manual specifies appropriate formulae to be used to calculate the safety distance envelope for each hazard likely to be encountered in the demolition procedure. The method used to determine the fragmentation safety distance distinguishes between single item and multi-item demolitions, and in particular prescribes a significantly increased safety distance for a multi-item demolition compared to a single item of similar size. In practise this means that in many situations munitions can only be disposed of singly, which is both costly and time consuming due to the safety procedures required between each blast. As a consequence, Logistic Command have requested AMRL to investigate the relative safety distances associated with single and multi-item demolition operations to determine charge configurations which would negate the cumulative effects arising from multi-item demolitions and allow a less restrictive formula to be applied.

The problem was first approached by examining the basis for the current formulae given in the Defence Explosives Safety Manual to establish the validity or otherwise of the formulae. A definitive result could not be obtained however and so a literature survey was conducted to ascertain the availability of any published data which could be used to modify or replace the current formulae. Significant information on enhanced fragment velocity effects from multi-item demolitions was obtained from this search, but it was not in a form which could be easily applied to the current problem. Discussions were then held with a number of noted overseas and Australian experts in the area of terminal effects and a workable solution to the problem was obtained by adopting a particular charge configuration. Calculations were also performed to determine whether there would be any blast enhancement resulting from the particular charge configuration recommended.

The major conclusions of this work are as follows:

1. There appears to be no evidence to support either the basis or the validity of the particular restrictive safety distance formula quoted in the Defence Explosives Safety Manual for stacked multi-item fragmenting munitions.
2. Multi-item demolition events do result in increased fragmentation hazards resulting from cooperative effects from adjacent munitions. However, due to the complexity of these effects simple formulae to determine appropriate safety distances in these circumstances have not yet been derived.

3. It is recommended that the restrictions on multi-item demolitions imposed by the manual be avoided by arranging the ordnance in a linear array (connected by det cord), rather than a stack, and by detonating the line simultaneously using a single detonator. Provided the items are more than one charge diameter apart there will be no cumulative effects to enhance the velocity of the fragments, and provided the safety distance is at least equal to that imposed by the blast limitation for the NEQ the linear charge array will not result in any enhanced blast overpressure effects.

As an example of the utility of this recommendation we consider some representative disposal operations at the Myambat demolition ground in NSW. Typical items for disposal would include 105 HE (3.43 kg), 155 HE (6.98 kg), and 155 HERA (10.43) kg, and up to several thousands of these items may be required to be disposed of at any one time. Myambat has a range boundary of 840 m, and application of the existing blast and fragmentation safety distance formulae imply that 62 rounds of 105 HE can be stacked and functioned at once, but only one 155 round can be functioned per firing. Adoption of the above recommendation would allow the disposal of 30 rounds of 155 HE per firing, which would result in considerable savings in both materiel costs and manpower time. In the above example, if each of the 155 rounds was disposed of singly then a detonator would be required for each round, whereas if the 30 items were arranged in a line and connected by det cord then only one detonator (and a relatively short length of det cord) would be required. Detonators cost on the order of \$10 each, and when several thousand items are to be disposed of the reduction in cost is significant.

Authors

D.A. Jones

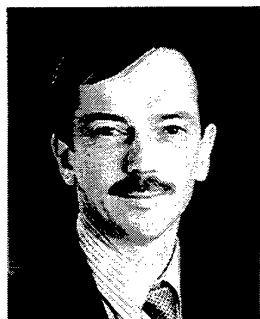
Weapons Systems Division



David Jones graduated from Monash University in 1972 with a BSc (Hons). He obtained his PhD from Monash in 1976. His thesis was titled "Anisotropic diffusion in the Townsend-Huxley experiment". After working at Strathclyde University, London University and the University of New South Wales he joined AMRL in 1983. He has worked on the numerical modelling of shaped charge warheads and slapper detonator devices. From February 1987 to May 1988 he was a Visiting Scientist at the Laboratory for Computational Physics and Fluid Dynamics at the Naval Research Laboratories in Washington DC. While there he worked on advanced computational fluid dynamics.

G. Kemister

Air Operations Division



Gary Kemister graduated from Sydney University in 1980 with a B.Sc (Hons I) and in 1985 with a Ph.D in theoretical chemistry. After working at Oxford University, University of North Carolina at Chapel Hill, Sydney University and La Trobe University on various aspects of electronic structure of materials he joined the Defence Department in 1991 working for the Analytical Studies Unit in Force Development and Analysis Division in Canberra. In 1993 he moved to Explosive Ordnance Division (now part of Weapons Systems Division) at Maribyrnong where he worked on numerical simulations of the physics and chemistry of explosions. In February 1997 he moved to Air Operations Division.

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1. Introduction

The destruction of unwanted munitions is a continuing activity for Army. Explosives can be destroyed either by detonation or burning, and these procedures can only be conducted on approved burning and demolition grounds, which are areas specifically designated for the controlled disposal of explosives and are licensed for this purpose. The licence specifies the disposal procedures approved for use on the particular site, as well as the Net Explosive Quantities (NEQs) for each authorised disposal procedure and Hazard Division [see Ref. 1 for further details]. The Defence Explosives Safety Manual [1] specifies appropriate formulae to be used to calculate the safety distance envelope for each hazard likely to be encountered in the demolition procedure. In particular, all fragments and projectiles should remain within the demolition range areas, and blast overpressures should not exceed 0.2 kPa outside the demolition range areas. The method used to determine the fragmentation safety distance distinguishes between single item and multi-item demolitions, and in particular prescribes a significantly increased safety distance for a multi-item demolition compared to a single item of similar size. In practise this means that in many situations munitions can only be disposed of singly, which is both costly and time consuming due to the safety procedures required between each blast. As a consequence, Logistic Command have requested AMRL to investigate the relative safety distances associated with single and multi-item demolition operations to determine charge configurations which would negate the cumulative effects arising from multi-item demolitions and allow a less restrictive formula to be applied.

The formula for the fragmentation safety distance for multi-item demolitions described in [1] can be traced to an earlier DSTO report by Oliver [2]. The purpose of this report was to provide reasonably reliable guidance for the prediction of the minimum safe height for aircraft in the vicinity of an explosive ordnance test facility. Detailed derivations were presented of the formulae to be applied to provide protection against fragmentation from single items, and the effects of blast from the net explosive quantity (NEQ). The calculation of the fragmentation safety distance for stacked or multi-item demolitions was presented in a less rigorous manner however, and was intended to be used only as a guide in determining minimum safety distances for stacked munitions. In the original report Oliver discusses several applications of the formulae and notes that "This example illustrates the difficulties which will result from an uncritical application of the formula for stacked munitions", ie. a severe limitation on the number of items which can be fired simultaneously, and also comments "What rule to apply for determining the vertical safety distance for fragmentation when only a few munitions are to be fired simultaneously, particularly when they are not collected in a compact stack, is at present uncertain". The purpose of this report is to address this question, and to provide a workable solution to the limitations imposed by the current documentation.

In the next section we describe the formulae used to calculate fragmentation and blast safety distances, and discuss an example which illustrates the severe limitation

imposed on demolition operations by the multi-item fragmentation formula. In section three we briefly describe the derivation of the formula for fragmentation safety distances for multi-item events given in [2] to highlight the assumptions made in the derivation, and to illustrate the approximate nature of the result. In section four we survey the available experimental data on blast and fragmentation effects from multi-item demolition trials. The small amount of data available does not allow us to either confirm or deny the validity of the safety distance formula given in [1,2], and so we have adopted a different approach to the problem. At the suggestion of Logistics Command [3] we have investigated the fragmentation hazard from a line of charges, rather than a compact stack of charges. Provided the charges are placed more than one charge diameter apart there will be no enhanced fragmentation effects, and this procedure would allow the restrictive multi-item safety distance formula to be overcome. A possible problem with this charge geometry however would be an enhanced blast overpressure at certain locations due to the highly directional nature of the blast. In section five we describe the results of three-dimensional air blast calculations which show that there is a pronounced directional blast effect, but this is limited to near field locations, and at distances specified by the blast safety distance formula given in [1,2] these directional effects have disappeared and the blast is identical to that from a spherical charge of equivalent weight.

2. Description of Problem

As specified in the Defence Explosives Safety Manual [1], when the hazard envelope for an item or items of ammunition and explosive is not known, the following formulae are to be used to determine horizontal safety distances. The greatest distance calculated is to be applied. (in the following formulae, D represents the safety distance in metres)

(a) Blast Safety Distance:

$D = 140 Q^{1/3}$, where Q is the net explosive quantity in kg of the explosive being destroyed

(b) Fragmentation Safety Distances:

(i) Single ammunition item or encased bulk explosive, $D = 370 W^{1/5}$, where W is the total mass in kg of the item being destroyed (ie. case plus charge).

(ii) Stacked Munitions, $D = 650 W^{1/5}$, where W is the mass in kg of the largest single item in the stack.

Consider a typical demolition ground with a range boundary of 840 m (Myambat, NSW). Application of the above formulae results in the following restrictions on charge weight: the blast limit implies that a maximum weight of 216 kg can be

destroyed in one firing, while the fragmentation limits imply maximum charge weights of 60 kg for a single ammunition item, or 3.6 kg for stacked ammunition.

Typical items for disposal would include 105 HE (3.43 kg), 155 HE (6.98 kg), and 155 HERA (10.43) kg. The above restrictions imply that 62 rounds of 105 HE can be stacked and functioned at once, as 3.43 kg is below the limit of 3.6 kg for the largest single item in the stack, and $62 \times 3.43 \text{ kg} = 212.66 \text{ kg}$, which is below the 216 kg limit imposed by the blast formula. Similarly, 30 rounds of 155 HE could be functioned at once and still comply with the blast limit, but the formula for stacked munitions implies that only one 155 round can be functioned per firing. This is a considerable inconvenience when large numbers (up to several thousand) of these items have to be disposed of, and also appears to be a rather artificial consequence of the above formulae, as it is difficult to imagine any mechanism which would result in the 30 rounds of 155 HE producing a significantly greater fragmentation hazard than the 60 rounds of 105 HE.

3. Basis for the Multi-Item Fragmentation Formula

It is instructive to examine the arguments leading to the formulae for the fragmentation safety distances described in the previous section. While not specifically stated within the Defence Explosives Safety Manual [1], it appears that the formulae originated in the report by Oliver [2]. The fragmentation safety distance for a single item reported in [2] was taken from an ARE Report [4], after conversion into S.I. units from the original Imperial units. It is apparently an approximation to a criterion introduced by the Ordnance Board in 1959, such that only one fragment per shot is expected to go beyond the formula distance. According to Jarret [5], by using the above formula for the safety distance "The probability of hitting a 4 ft square target with a direct fragment at this distance is less than 10^{-6} ."

Oliver then discusses stacked munitions, and derives the formula $D = 650 W^{1/5}$ by using the formula for a single cased item in combination with several plausible assumptions. The main assumption is that fragments from the outermost munition in the stack will receive additional acceleration from the blast from the innermost munitions. As Oliver notes "The magnitude of this effect cannot be precisely estimated, but an upper limit can be assigned". Oliver derives this upper limit by noting that "the gases generated by the detonation of a bare charge of high explosive leave the surface with a velocity which, for some explosives, may be as high as 4600 m/s. This velocity may be taken as the greatest velocity achievable by an explosively propelled fragment". Oliver then uses this velocity in an equation which calculates the maximum horizontal range of a fragment with a given initial velocity and mass, and then compares the results with safety distances calculated from the single item formula. For a variety of examples, ranging from 105 mm shells to 500 lb bombs, the assumption of a maximum velocity of 4600 m/s resulted in an increase in the horizontal range of no more than 25%, when realistic values for the masses of the fragments were employed. In some instances the range was increased by 50%, but the

fragment masses which produced these enhanced ranges were considered unlikely. Hence Oliver concluded "This and other calculations suggest that for stacked munitions an increase of 50% over the formula distance for single munitions could be fairly safe, and a 75% increase would be almost certainly safe. Applying the latter figure yields $D = 650 W^{1/5}$ for stacked munitions."

It should be noted that if Oliver had considered the increase of 25% in the horizontal range to be a realistic and acceptable safety distance for stacked munitions (this would have been a plausible recommendation) then the safety distance formula would have become $D = 460 W^{1/5}$. In this case the maximum charge weight for the largest single item in a stack for the example described in the previous section would be 20.3 kg, and then both the 155 HE and the 155 HERA could be stacked and detonated simultaneously.

It should also be noted that the main focus of Oliver's calculations in [2] was to deduce safety distance formulae for aircraft flying over a demolition ground containing a known weight of explosive. In this case there is every reason (and no penalty) for being overly cautious. Oliver did note however that if the multi-item fragmentation formula was used in reverse, ie. to deduce a maximum weight for a given distance, then the resulting charge weights would be severely restricted and result in unrealistically excessive safety margins. Unfortunately little notice appears to have been taken of these comments and the safety distances derived by Oliver for safe airspace requirements have been adopted for general use.

As can be appreciated from the above discussion, the restriction imposed on multi-item demolitions from the use of the formula for stacked fragmenting munitions is overly cautious, and has not been derived from a rigorous analysis. In view of the severe constraints which the formula imposes on demolition operations it seems reasonable to examine the issue in more detail, and to suggest an alternative procedure for multi-item demolitions which has an acceptable safety standard, but which allows the conduct of more efficient demolition operations. In the next section we review the available literature on stacked demolition events and consider this proposal in more detail.

4. Literature Survey of Stacked Multi-Item Demolition Events

An extensive literature search has failed to find any detailed discussion of the fragment velocity enhancement mechanism used as the basis for the multi-item fragmentation formula quoted in OPSMAN 3. Pratt and Clark [6] have described numerical simulations of the physical processes involved in the flow of fragments within a detonating bomb stack, including the effect of blast winds generated from the detonating explosive, but they concluded, at least for Mark 82 bomb fragments, that the case fragments are massive enough and have a small enough frontal area that the

blast winds cannot significantly influence their trajectory while they are travelling within the bomb stack.

In the absence of any significant literature information on the fragment velocity enhancement mechanism described in the previous section discussions were held with a number of noted overseas and Australian experts in the area of terminal effects. These included Dr. R. Frey, Army Research Laboratory, Aberdeen, USA, Michael Swisdack Jr., Naval Surface Warfare Center, Indian Head, USA, and Michael Chick, Aeronautical and Maritime Research Laboratory, Melbourne, Australia. The general consensus regarding the blast enhancement mechanism described by Oliver, ie. the blast from one munition enhancing the velocity of fragments from another, was that the mechanism had no credibility.

Enhanced fragment velocities do arise in the case of stacked munitions however and these have been well documented in the work of Ramsey, Powell and Smith [7], Powell, Smith and McCleskey [8], and Ward [9]. The work of Powell and Smith was sponsored by the US Department of Defense Explosives Safety Board (DDESB) to provide the DDESB with the necessary fragmentation data to improve the current US quantity-distance standards. Reference [7] reported experimental findings from the simultaneous detonation of Army M107 155 mm projectiles stacked in various pallet configurations, while reference [8] reported results from the detonation by means of natural communication (ie. sympathetic detonation) of 155 mm projectiles stacked in various storage configurations. The experimental results showed that when a stack detonates the velocity, size, and spatial distribution of the fragments may be significantly different from that which would be obtained from an equivalent number of single munition firings. Ramsey, Powell and Smith [7] found that when two adjacent warheads detonate an interaction zone forms between them which produces a concentrated jet of fragments with velocities considerably in excess of those obtained from a single detonating warhead. For the case of 155 mm projectiles increased velocities of up to 75% were observed. Similarly, Ward [9] noted a 45% increase in fragment velocity when a pallet load of six Mk 82 bombs was sympathetically detonated.

Powell and Smith were able to give simple rules for computing the number and velocity of the fragments from a large stack in terms of the fragments obtained from two warheads detonated side by side, but they noted that their methodology had limitations, and was not able to be applied to other mass detonating munitions. Little work on the problem appears to have been done since this time, and the current US DOD Ammunition and Explosives Safety Standards regulations specify relatively simple criteria to be followed on ranges used for explosive ordnance disposal. These regulations [10] specify a minimum separation distance of D (in Feet) = $328 W^{1/3}$, but not less than 1250 ft for non fragmenting explosive materials. For fragmenting munitions the minimum separation distance is again D (in Feet) = $328 W^{1/3}$, but not less than 2500 ft, for bombs and projectiles having a diameter less than 5 inches. For munitions with a diameter greater than 5 inches the minimum distance is 4000 ft. In addition, the regulations state that "The maximum fragment throw range (including

the interaction effects for stacks of items or single items, whichever applies), with an appropriate safety factor, may be used to replace the 2500 ft or 4000 ft minimum ranges". The Safety Standards do not specify how the maximum fragment throw range for stacks should be calculated, and they do not specify how an appropriate safety factor can be calculated. In practice, approximately 1/2 to 1/3 of all demolition firings in the USA are multi-item events. A common method of overcoming the fragmentation safety problem is to bury the items in pits. A soil cover of approximately 5 to 10 feet ensures that the fragment range will be zero [11].

From the literature survey and our discussions with noted experts in the area of terminal effects we are able to make several observations:

1. There appears to be no evidence to support either the basis or the validity of the particular restrictive safety distance formula quoted in OPSMAN 3 for stacked multi-item fragmenting munitions.
2. Nevertheless, multi-item demolition events do result in increased fragmentation hazards resulting from cooperative effects from adjacent munitions. Due to the complexity of these effects however simple formulae to determine appropriate safety distances in these circumstances have not yet been derived.

As we can neither conclusively disprove the validity of the multi-item fragmentation formula quoted in OPSMAN 3, nor provide a simple and well proven set of formulae to replace it, other solutions to the problem must be found. As mentioned above, a simple solution commonly employed in the USA is to use a layer of soil to reduce the fragment range to zero. In this report we have followed a solution proposed by Maj. B. Schiefelbein [12]. As an interim measure, the restrictions on multi-item demolitions imposed by the OPSMAN 3 manual can be circumvented by arranging the ordnance in a linear array (connected by det cord), rather than a stack, and by detonating the line simultaneously using a single detonator. In this way we avoid the complications arising from the cooperative effects which occur in stacked munitions. Our discussions with experts in the terminal effects area and the results of our literature survey indicate that if the munitions are arranged in a linear array and are located more than one charge diameter apart then there will be no cumulative effects to enhance the velocity of the fragments, and the fragmentation safety distance should be equal to that from a single item event.

Whilst the fragmentation safety distance should be equivalent to that from a single item event for linear arrays, it is unclear how the distribution of blast overpressure will be affected by a change from spherical to linear geometry. Certainly in the near field we expect to see pronounced directional effects, but it is unclear how far these will persist in the flowfield. Consequently, in the next section we perform a series of numerical simulations to investigate the blast distribution patterns from several different charge arrangements.

5. Airblast Calculations for Multi-Item Demolitions

A number of airblast simulations have been conducted using the AMRL 3D airblast code to quantify the effect on the far field blast overpressures of distributing the net charge in a variety of configurations. Three charge configurations were chosen for detailed calculations, and the NEQ of each configuration was 52 kg of TNT. In the first configuration the entire 52 kg was located at the origin of a three-dimension cartesian grid. The positive z direction was taken to correspond to vertical height, and a reflecting boundary condition was imposed at $z = 0$ to represent the ground. Outflow boundary conditions were applied to each of the boundaries in the x and y directions. Hence this first configuration represents the case of a single item demolition of 52 kg located on the ground.

In the second configuration the 52 kg of TNT was divided into four 13 kg lots and placed at the corners of a square array, with a minimum distance between each charge of 300 cm. In the third configuration the charge was divided into six lots of about 8.7 kg and arranged in a linear array, with a spacing of 100 cm between each charge. Blast overpressures as a function of time were recorded at several locations for each charge configuration. For the single 52 kg charge located at the origin the pressure was recorded at distances of 7, 14, and 21 m from the charge centre. For the distributed system of four 13 kg charges the pressure was recorded at distances of 7, 14, and 21 m from the centre of the charge array along a diagonal passing through one of the charges. For the last configuration the pressures were recorded at distances of 7, 14, and 21 m from the centre of the charge array in each of two directions; either along the line formed by the six charges, or perpendicular to the line. Figure 1 shows a plan view of each of the charge configurations used in the calculations.

The simulations were performed using a three-dimensional computational fluid dynamics computer program known as BLAST3D, which was developed at AMRL and has been described in several recent publications [13-16]. The code solves the Euler equations for the conservation of mass, momentum, and energy for an inviscid, compressible fluid. Operator splitting is used to reduce the complexity of the three-dimensional calculations by converting them into three equivalent one-dimensional calculations, and the resulting one-dimensional equations are solved using the Flux Corrected Transport (FCT) algorithm of Boris and Book [17]. This has fourth order phase accuracy, and an overall second order accuracy on uniform grids.

The simulations were performed on a three-dimensional Cartesian grid with fixed grid spacing defined by $\Delta X = \Delta Y = \Delta Z = 10$ cm. The calculations were run on a HP 9000 work station and each run required approximately four days of CPU time. A pressurised sphere model was used to start the calculations. In this method a small region of the grid, representing the initial explosive charge, is set to an initial pressure of 1000 atmospheres and a temperature of 3000 K. The volume of the sphere is chosen so that the energy contained within the sphere corresponds to the detonation energy of the equivalent weight of TNT. This approach considerably simplifies the explosive

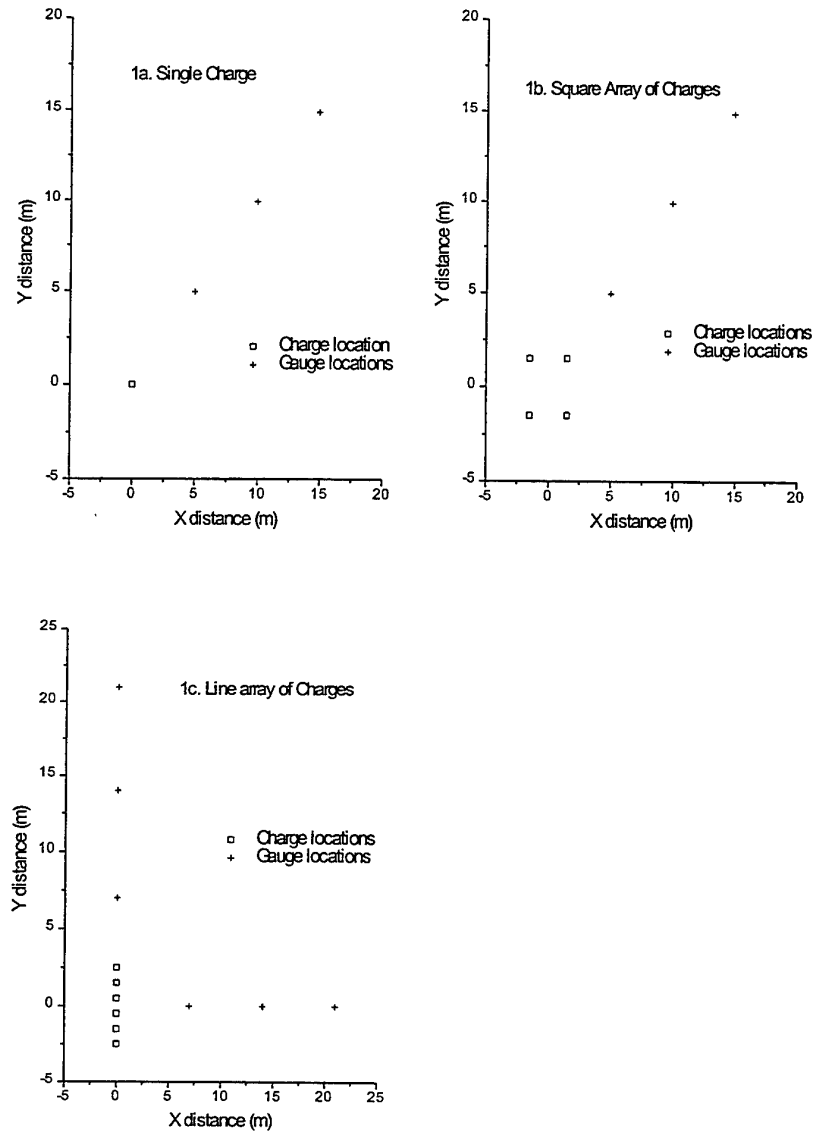


Figure 1. Plan view of the three configurations used in the calculations

modelling as it removes the need to follow the detailed detonation processes occurring within the condensed explosive.

Figure 2 shows plots of pressure as a function of time for each of the charge configurations at the 7 m recording position. Figure 2a for the single charge shows the expected ideal blast profile; the pressure rises abruptly to a peak of approximately 300 kPa at approximately 5 ms, the pressure then decays to ambient in a further 5 ms, then drops to a partial vacuum before the secondary shock restores the pressure to ambient conditions by about 26 ms. These results are in good agreement with the CONWEP code [18], which predicts an arrival time of 5.6 ms, a positive phase duration of 7.6 ms, and a peak overpressure of 330 kPa. Better agreement could be obtained by using a finer grid spacing for the calculations, but this level of accuracy is unnecessary for the comparative calculations considered here.

Figure 2b shows the equivalent record for the distributed charge. We now see two clearly resolved peaks, the first of these being the blast from the nearest 13 kg charge located approximately 5 m from the recording location. This has a peak pressure of approximately 260 kPa, while CONWEP predicts a peak overpressure of 245 kPa. 5 m from a 13 kg charge. The second peak arises from the coalescence of the blast from the next two charges equidistant from the recording position. It is interesting to note that the distributed nature of the charge results in a much weaker secondary shock, which is observable after approximately 24 ms.

Figures 2c and 2d show the pressure as a function of time for the linear charge array 7 m from the centre of the charge, both along the line of the charge and perpendicular to the line respectively. The strong single pulse in Figure 2c is the shock from the first of the six 8.66 kg charges, which is located 4.5 m from the recording position. This has a peak pressure of approximately 270 kPa, which is in good agreement with the CONWEP prediction of 230 kPa 4.5 m away from the blast of a single 8.66 kg charge. The shock fronts from each of the remaining five charges have yet to coalesce with the lead shock, and are visible as smaller peaks in the negative phase of the primary shock. Figure 2d shows a single smooth shock profile similar to figure 2a, but with a much higher peak pressure of approximately 520 kPa. This occurs because the individual 8.66 kg charges are able to coalesce much more quickly in this direction and hence strengthen one another, leading to the higher peak pressure and a correspondingly shorter negative phase duration.

Figure 3 shows plots of pressure as a function of time for each of the charge configurations at the 14 m recording position. Figure 3a for the single charge again shows a single shock profile with a peak pressure of approximately 67 kPa, which compares well with the CONWEP prediction of 73 kPa. There is a slight perturbation to the flow at approximately 30 ms which could be caused either by numerical signals from the edge of the grid propagating back into the flow, or by the initial non-spherical shape of the charge, which because of the cartesian nature of the grid is approximated as a cube.

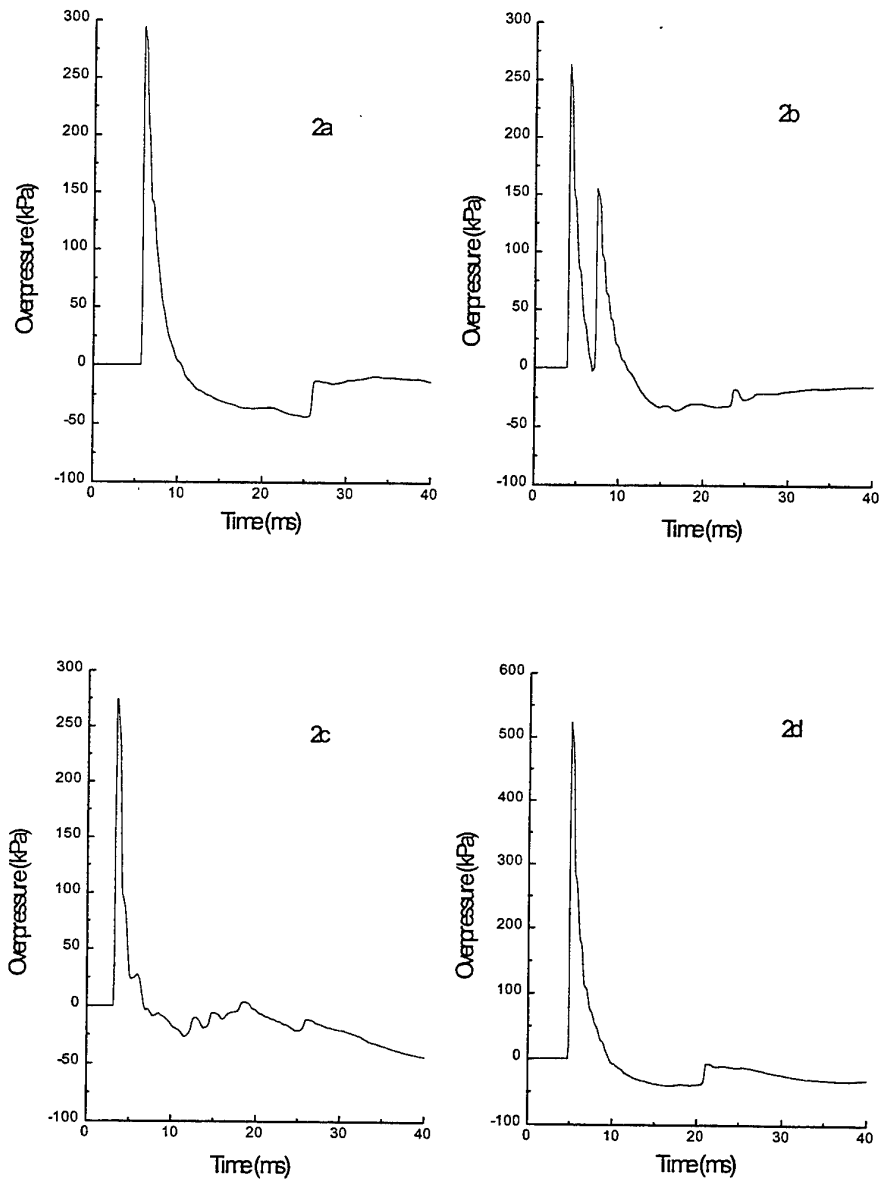


Figure 2. Pressure-time plots at 7 m from the origin of the charge for the single charge (2a), the distributed charge (2b) and the linear array (2c - parallel, 2d - perpendicular).

Figure 3b shows the profile for the distributed charge. The two distinct peaks previously shown in Figure 2b have now almost coalesced. The peak pressure is approximately 50 kPa, which is lower than the peak value for the single charge at the same distance, but the length of the positive phase duration is slightly longer than that for the single charge.

Figures 3c and 3d show the pressure as a function of time for the linear charge array 14 m from the centre of the charge both along the line of the charge and perpendicular to the line, respectively. The individual shocks which were visible as smaller peaks in the negative phase of the primary shock in Figure 2c are now much more visible, but the peak pressure from any of these is less than the peak value from the single charge. Figure 3d continues to show a single relatively smooth shock profile, with a peak overpressure of approximately 94 kPa. This is still considerably higher than the peak pressure from the single charge at this distance, but the difference is less than that measured only 7 m from the charge origin.

Figure 4 shows similar plots at the 21 m recording position. Figure 4a shows a single shock profile with a peak pressure of approximately 36 kPa, which compares well with the CONWEP prediction of 35 kPa. The perturbation which was evident at 30 ms in Figure 3a has moved up in the positive signature and the two peaks will eventually coalesce to form a single shock front. This is similar to the behaviour shown in Figure 4b, where the two peaks at the shock front which were present in Figure 3b have already coalesced to produce a single shock front with a peak overpressure of approximately 36 kPa, in agreement with the value obtained from the single charge. Hence we see that even at the relatively short distance of 21 m the blast overpressure from the four distributed 13 kg charges is equivalent to that from the single 52 kg charge.

Figure 4d shows that even the much higher peak pressure which was obtained in a direction perpendicular to the linear array of six 8.66 kg charges has also decayed at a distance of 21 m. The peak pressure in Figure 4d is also approximately 36 kPa, and the positive phase duration is similar to the values shown in Figure 4a and 4b. The pressure measured along the charge line still shows contributions from each of the individual charges, but the magnitude of the individual peaks is less than that from the single charge. These individual shocks will shortly coalesce, and the blast in either direction from the linear array will be equivalent to that from the single 52 kg charge.

The blast safety distance for a single 52 kg charge computed from the formula $D = 140 Q^{1/3}$ is 522 m, while the above calculations show that the blast overpressure from either of the distributed charge arrays is equivalent to that from the single charge at distances of approximately 20 m. While the calculations have shown that for a linear charge array there is a pronounced directional effect in the near field, they have also shown that these effects are washed out in the far field, and that the blast overpressures are equivalent to those from a single charge at distances determined by the blast safety distance formula. Although we have presented results from only three calculations we believe that the above results will be true in general, ie. for the charge weights, charge

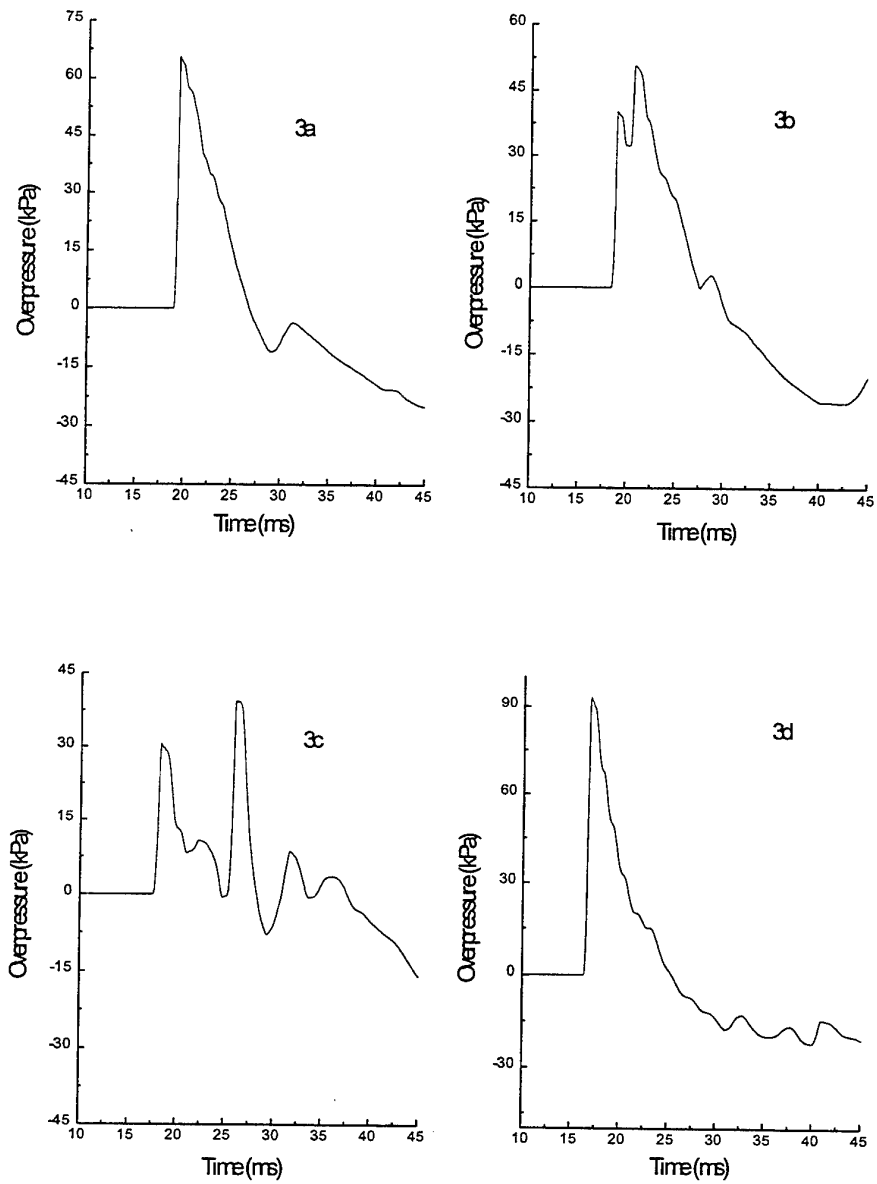


Figure 3. Pressure-time plots at 14 m from the origin of the charge for the single charge (3a), the distributed charge (3b) and the linear array (3c - parallel, 3d - perpendicular).

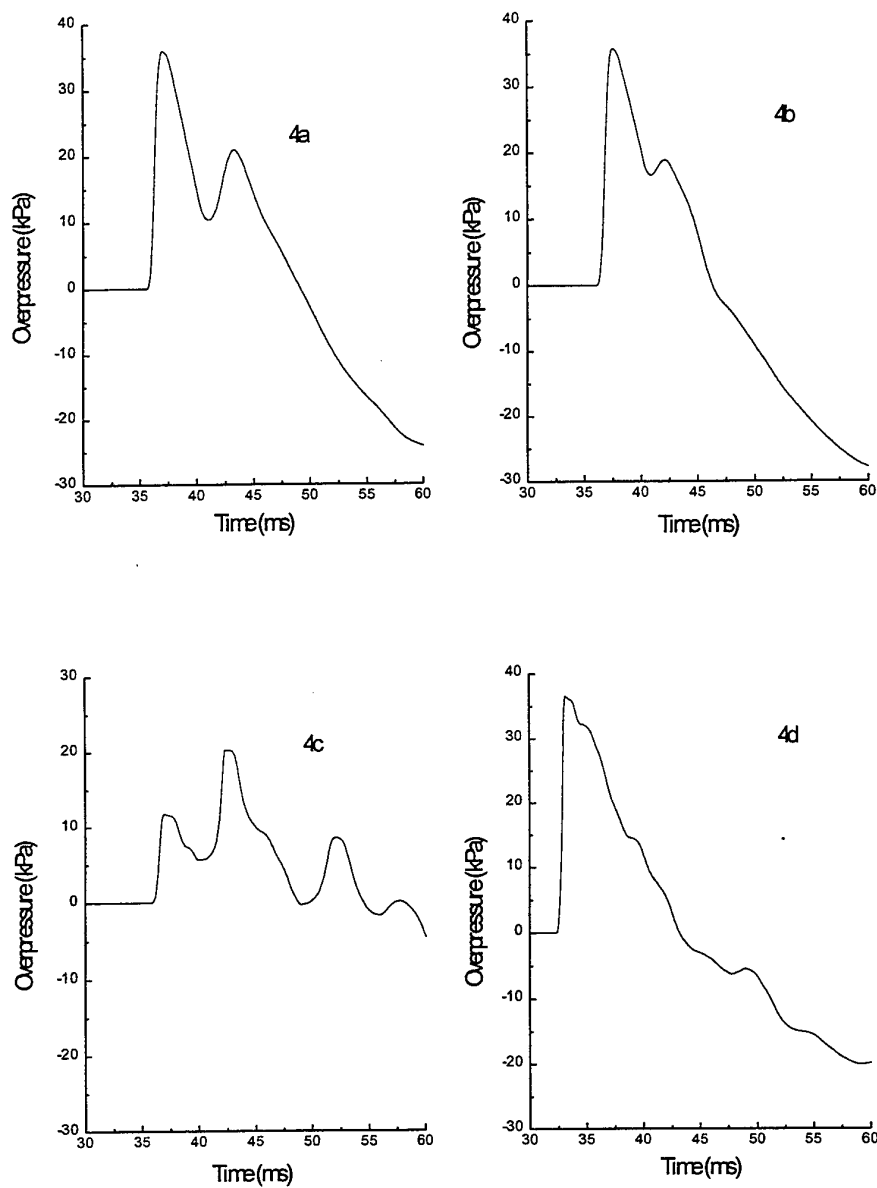


Figure 4. Pressure-time plots at 21 m from the origin of the charge for the single charge (4a), the distributed charge (4b) and the linear array (4c - parallel, 4d - perpendicular).

distributions, and distances involved in typical demolition operations we expect that the blast overpressures at distances determined by the blast safety distance formula will be entirely independent of the manner in which the munitions are distributed.

6. Conclusions and Recommendations

The major conclusions of this work are as follows:

1. There appears to be no evidence to support either the basis or the validity of the particular restrictive safety distance formula quoted in OPSMAN 3 for stacked multi-item fragmenting munitions.
2. Multi-item demolition events do result in increased fragmentation hazards resulting from cooperative effects from adjacent munitions. However, due to the complexity of these effects simple formulae to determine appropriate safety distances in these circumstances have not yet been derived.
3. It is recommended that the restrictions on multi-item demolitions imposed by the OPSMAN 3 manual be avoided by arranging the ordnance in a linear array (connected by det cord), rather than a stack, and by detonating the line simultaneously using a single detonator. Provided the items are more than one charge diameter apart there will be no cumulative effects to enhance the velocity of the fragments, and provided the safety distance is at least equal to that imposed by the blast limitation for the NEQ the linear charge array will not result in any enhanced blast overpressure effects.

As an example of the utility of this recommendation we refer to the example discussed in Section 2 of this report, which described typical disposal operations at the Myambat demolition ground. It was noted there that the current fragmentation safety distance formulae would allow 62 rounds of 105 HE (3.43 kg) to be stacked and functioned at once, while only one 155 HE (6.98 kg) round could be functioned per firing. Adoption of the above recommendation would allow the disposal of 30 rounds of 155 HE per firing, which would result in considerable savings of time and effort.

7. Acknowledgments

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D.A. Jones and G. Kemister

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NSWC, Indian Head Division, Code 950, White Oak, MD 20903-5640, USA

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19. ABSTRACT The destruction of unwanted munitions is a continuing activity for Army. The Defence Explosives Safety Manual specifies formulae which prescribe a significantly increased safety distance for a multi-item demolition compared to a single item of similar size. In practise this means that in many situations munitions can only be disposed of singly, which is both costly and time consuming due to the safety procedures required between each blast. This report examines the basis of the formulae and recommends a charge configuration which will enable multiple munitions to be disposed of in a single detonation.					